CATHETER CALIBRATION USING TEMPLATE MATCHING LINE INTERPOLATION ALGORITHM

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*Abstrac*t- **This paper presents a study case of specific angiographic X-ray image processing, such as quantitative cardiac analysis. During QCA it is very important to get precise and accurate results because these data are used to make a diagnosis or to plan an eventual intervention. The two main requests are influenced by many factors, such as: image resolution, type of the calibration, algorithm used for contour detection, size of the FOV, other parameters of the image. The studied calibration method is the one using catheter size, and it looks to find a general solution for all size FOVs and catheters. The algorithm can be implemented either on acquisition systems – in order to allow direct and fast quantification of the recorded sequences –, or on review stations – in order to enhance the 2D post-processing functionality.**
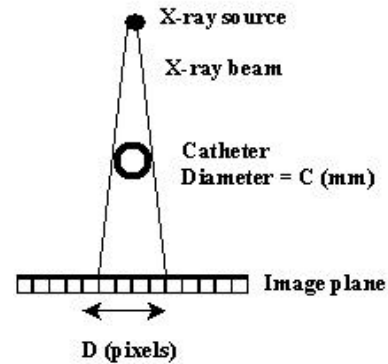*Keywords* **- X-ray angiography, QCA, catheter calibration.**

I. INTRODUCTION

Generally taken the QCA is a software tool used to examine the morphology of the vessels . Its basic medical need is to get different geometrical data: distances and lengths, diameters and volumes, percentage of stenosys, volume of aneurysm, but in some cases we can get information on the functional significance of lesions and artery obstructions. It is applied in many medical fields: diagnostic imaging, interventional cardiology, clinical investigation, etc.

Usually the basic features of this tool are: automatic or manual contour detection, sphere/catheter/grid calibration, stenosys and/or aneurysm detection and 2D/3D quantification, etc.

As in a multi-step process the errors are cumulative, it is important for each step to have a very good level of accuracy and precision. This study is focusing on the calibration step, more precisely on sub-pixel interpolation of parallel curves representing the outer diameter of the catheter.

II. METHODOLOGY

Within QCA, stenosys and aneurysm quantification can be done either by giving relative values of the examined structures (ex. percentage of the stenosys related to healthy vessels) or by giving exact values in millimeters, inches, etc. To be able to make the correspondence between the image plane and the real life objects, prior any measurement a calibration is needed. The result of the calibration will be a factor (calibration factor) which tells the proportion between the real size of the calibrating object (in mm) and the size of the calibrating object on the image plane (in pixels).

The calibration factor (the size of a pixel in mm) depends on the magnification factor due to the conic projection of the X-ray system. The magnification factor is the ratio between the distance from the X-ray source to the Image Intensifier (II) and the distance from the X-ray source to the artery [4].

Fig 1. Object space - Image space relation in X-ray imaging

Many type of objects can be used for calibration: ruler or grid placed on the table, metallic sphere placed on or hold by the patient and the catheter itself. The best and most precise results can be achieved by catheter calibration because usually the catheter has the same distance from the x-ray source as the examined vessel or heart. In case of the other methods we can easily make over- or under estimations.

Principles of the catheter calibration. Generally all calibration methods include three main steps: (1) geometric edge detection (finding the approximate contour of the calibrating object), (2) fine catheter edge interpolation (using a priori knowledge about the geometry of the calibrating object: parallel curves, circle), (3) parameter extraction.

(1) Edge detection.

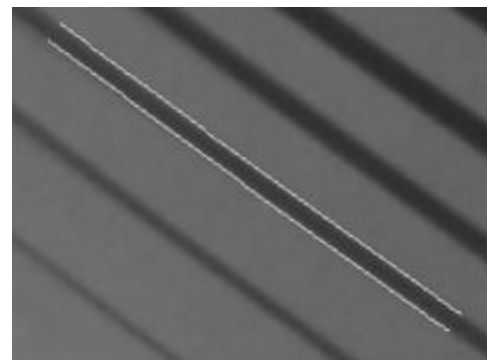There can be found many edge detection algorithms and many implementations of them in the bibliography.

Fig 2. Detected contours on an X-ray image

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Abstract

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Some of them are specialized on symmetric curvilinear structures and are combined with image filtering processes [1], others are specialized on ridge detection [2] (specific cases of full or empty catheters). Usually the result of this process can be a rejection (in case of unsuccessful edge detection in the ROI) or two sets of pixels forming the two outer edges of the catheter.

(2) Fine interpolation of the catheter edges.

The only available information to fine tune the automatically detected edges are the two sets of data, respectively the parallelism of the curves.

The goal is to define a method for estimating at sub-pixel level the mathematical equation of the original edge. To analyze one set of data (one edge) a parameterized-template matching algorithm is used [3], applied for lines. The method is based on the Hough transform that transforms the analyzed data from the "image space" to the "parameter space". In our case the image space is the image itself (x, y coordinates of the pixels), the parameter space is determined by following 2 coordinates: Θ – the angle between the line and the normal to that line (represented on the Ox), d – distance of the line from the origin (represented on the Oy). The transformer equation is quite simple:

$$x \cdot \cos \Theta + y \cdot \sin \Theta - d = 0$$

For each pixel (marked as part of the detected edge) of the image space we determine a list of lines that can go trough that pixel. The number of lines can be selected according to the desired precision and calculus capacity. (In case of resolution of 1° there will be 180 different lines)
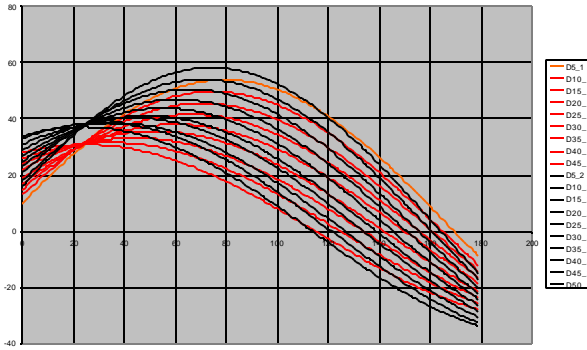

Fig 3. Family of classes in case of some control points. Each curve represents one class of lines

In the parameter space there can be identified 2 focal points where the two set of curves intersect each other. The precise coordinates of these points can be calculated either by simply averaging the coordinates of the intersections, or by using a more complex algorithm that first cuts the extremities then calculates a weighted average (the weights will be determined according to the number of lines that intersects in the given point) of the intersection coordinates.

For each curve all intersections in a discrete space are approximated by:

$$\Theta_{ij} = \Theta, \text{ where } \min\left(abs\left(dist[i][\Theta] - dist[j][\Theta]\right)\right)$$
$$d_{ij} = \left(dist[di][\Theta] + dist[j][\Theta]\right)/2,$$

where $i = i..N-1$, $j = (i+1)..N$, and $\Theta = 0..179$.

Simple method:

$$\Theta_{av\_q} = \frac{1}{N} \sum_{i,j=1}^{N} \Theta_{ij} \text{, and } d_{av\_q} = \frac{1}{N} \sum_{i,j=1}^{N} d_{ij} \text{, where } q = 1..2 .$$

Complex method:

$$\Theta_{av\_q} = \frac{\sum_{i,j=1}^{N} m_{ij} \cdot \Theta_{ij}}{\sum_{i,j=1}^{N} m_{ij}} \text{, and } d_{av\_q} = \frac{\sum_{i,j=1}^{N} n_{ij} \cdot d_{ij}}{\sum_{i,j=1}^{N} n_{ij}} \text{, where the}$$

value of m_{ij} and n_{ij} is determined by the multiplicity of the Θ_{ij}, resp. d_{ij} values.

The previously calculated values give the $(\Theta_{av\_q}, d_{av\_q})$ parameters of the two edges. Knowing that normally the two original lines are parallels, we will try to "paralellise" our lines. For that we calculate the mean of the two angles and we will use it as the final parameter for both lines ($\Theta_{overall}, d_{overall}$). Having the distances and the angulation we can determine the equation of the two parallel lines in the image space.

$$X_{0\_q} = \frac{d_{av\_q}}{\cos \Theta_{overall}} \text{ ; } Y_{0\_q} = 0 \text{ ;}$$

$$X_{1\_q} = 0 \text{ ; } Y_{1\_q} = \frac{d_{av\_q}}{\sin \Theta_{overall}} .$$

(3) Parameter extraction.

Geometrical characteristics are used to measure average distance between the edges detected at the previous step. This value and the manually entered catheter diameter size are used to calculate the calibration factor.

The distance between the two lines is given by:

$$D = abs(d_{av\_1} - d_{av\_2})$$

The calibration factor is:

$$F_{calib} = \frac{C(fr)}{3 \cdot D} \text{ (mm/pixel),}$$

where $C(fr)$ is size in french, 1/3 converts french into mm.

III. RESULTS

To test the line interpolation algorithm manually generated correct (straight) and wrong (curved, noisy) test-lines were used. In all cases the interpolated lines gave a very good approximation of the main orientation of the curves.

Further algorithm and calibration tests were performed using angiographic images generated by GEMS AdvantX LC+ system. The catheter calibration results were compared with the results produced by the mentioned acquisition system but the recorded differences raised up to 11%.

As it is shown in Fig. 4, the pixels detected as possible contour points are marked with squares, interpolated lines are drawn with dotted lines, adjusted lines with continuos lines. The dotted lines are obviously not parallel, but on the portion represented by the image elements (pixels) are well approximating the lines represented by them. By paralleling them actually we calculate the average distance between them.
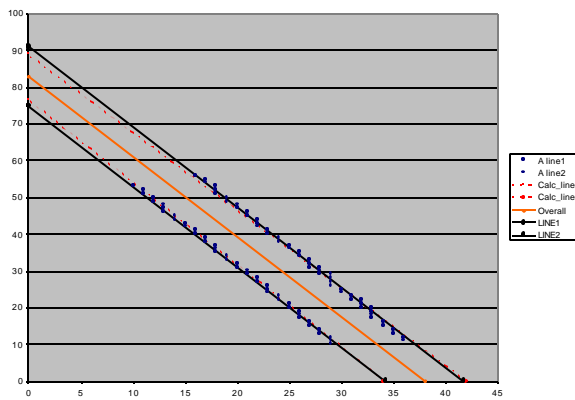

Fig 4. Original pixels, interpolated lines (dotted) and adjusted lines

IV. DISCUSSION AND CONCLUSION

The verification and validation process is still not completed. Different weighting methods are analyzed in order to increase accuracy. Grid phantoms were used to validate the measured distances. Preliminary error approximations show a maximum level of 13%.

The presented method seems to give a good estimation even in cases when the catheter is not straight and presents a curvature. In this case the calculated T_{av_q} angles will represent the averaged direction of the partial tangents to the curve.

An other approach to increase the accuracy of the edge detection and of the calibration results the algorithm could be extended to use not just one single image but a set of images belonging to the same sequence. Data processing using more than one frame could reduce the noise influence.

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